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Recent Advances in ZnO Nanoparticle Synthesis for Potential Applications

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ABSTRACT

Plant extracts provide a potential alternative to conventional chemical approach in the synthesis of metal oxide nanoparticles. Green synthesis has garnered a lot of attention as a dependable, long-lasting, and environmentally friendly way to make a range of metal oxide nanoparticles. Metal oxide nanostructures have gained a lot of attention due to their enormous surface area and high reactivity. Zinc oxide nanoparticles (ZnO NPs) have recently been explored for their antimicrobial, antifungal, anti-diabetic, anti-inflammatory, wound healing, antioxidant, and optical characteristics. This study aims to examine the green synthesis of ZnO NPs using a variety of plant extracts to satisfy the needs of large-scale industrial production ensuring biocompatibility, biodegradability, cost-effectiveness, and a and a lot of potentialities.

Introduction

Novel synthesis techniques for nanomaterials (such as metal nanoparticles, quantum dots (QDs), carbon nanotubes (CNTs), graphene, and their composites) have been a hot topic in nanoscience and technology during the previous decade [1]. Nanoparticles have been incorporated into a variety of consumer industries, including industrial, health, food, feed, space, chemical, and cosmetics, necessitating a green and environmentally friendly approach to their production [2]. Green synthesis is necessary to avoid the creation of undesired or hazardous by-products by developing dependable, long-term, and eco-friendly synthesis processes. The solvent, temperature, pressure, and pH conditions play a vital role in green synthesis based on biological precursors (acidic, basic, or neutral). Plant biodiversity has been widely explored for the production of metal oxide nanoparticles because of the abundance of beneficial phytochemicals in diverse plant extracts, particularly in leaves, such as ketones, aldehydes, flavones, amides, terpenoids, carboxylic acids, polyphenols, and ascorbic acids. Metal salts can be reduced into metal and metal oxides nanoparticles by these components [3]. We highlighted the present status of research on the green synthesis of ZnO NPs nanoparticles, as well as the benefits of this technique over chemical synthesis. Our objective is to provide a comprehensive description of "green" synthesis processes ZnO NPs and their related components that will help researchers working in this growing field and as a valuable reference for readers interested in this issue.

Conventional Synthesis of ZnO Nanoparticles

Metallic oxides nanoparticles, such as ZnO NPs, may be prepared using two distinct methods: mechano-chemical and chemical. Chemical synthesis includes sol-gel, hydrothermal, co-precipitation, and micro-emulsion processes, all of which are considered traditional methods. Mechano-chemical synthesis includes protocols that use laser ablation and high-energy ball milling techniques, whereas chemical synthesis includes sol-gel, hydrothermal, co-precipitation, and micro-emulsion processes.

Sol-Gel Techniques

The sol-gel process was used to create a zinc oxide nanostructure. 2 g zinc acetate is required to make a sol. A weighing balance was used to weigh the dihydrate and 8 g of sodium hydroxide. Then 2 g zinc acetate dihydrate was dissolved in 15 ml distilled water, and 8 g sodium hydroxide was dissolved in 10 ml distilled water for five minutes. After that mix two solutions and stir the mixture using a magnetic stirrer. Then the mixture is titrated dropwise using a burette filled with 100 ml ethanol. A white precipitate was obtained as a result of the reaction. [4].

Hydrothermal Technique

Hydrothermal synthesis of ZnO nanorods was carried out at 110°C utilizing the Zn $(OH)_4^{2-}$ precursor in an alcohol solution. Zn $(CH_3COO)_2.2H_2O$ and NaOH were dissolved in deionized water to produce $[Zn^{2+}]$ = 0.50 mol/L and [OH] = 5.00 mol/L, respectively. After that, the precursor solution and pure alcohol were combined in an autoclave and brought to room temperature. The items were then dried after being rinsed with distilled water and alcohol. The UV emission in photoluminescence (PL) is 400 nm due to rod flaws [5].

Co-Precipitation Techniques

ZnO NPs are created using this approach by simultaneously nucleating, growing, and agglomerating tiny nuclei. The simplicity, lack of a high-temperature demand, and overall energy economy are all advantages of this approach. batch-to-batch repeatability issues, poor particle size distribution, and significant agglomeration are among the disadvantages [6].

Laser Ablation Techniques

A laser beam is used to remove metallic ions from a metal surface while submerged in a tiny volume of liquid, such as methanol, ethanol, or distilled water, in a traditional laser ablation process. This approach has the advantages of simplicity and a very safe procedure from an environmental standpoint, resulting in a method that is both efficient and simple to conduct [7].

High-Energy Ball Milling Techniques

In a high-energy shaker mill, rigid balls are used to generate fine metal NPs using a high-energy ball milling method. The smaller the particle size, the longer the ball milling time. Spherically formed ZnO NPs with a particle size of about 30 nm were found in the sample processed for 50 hours [8].

Micro-Emulsion Technique

This technique led to a rapid reactant exchange causing a precipitating reaction in nano-droplets and subsequent nucleation growth, and NPs were stabilized by the presence of a surfactant. The ZnO NPs were made by drying the solid product at 130°C for two hours and then calcining it at 550°C for three hours [9].

Nanotechnology for Green Synthesis of ZnO NPs

Green nanotechnology aims to eliminate harmful byproducts of the synthesis process. As a result, the use of green nanotechnology principles in the synthesis of ZnO NPs has resulted in the development of three major types of processes, which may be characterized as follows:

a) Microbiologic and bacterial extracts often used for bacterial synthesis.

b) Natural extract-mediated biosynthesis, mainly with plants and different algae; and

c) Biomolecular and biomolecular-mediated biosynthesis, using organisms such as carbs or structural biopolymers that are isolated from organisms such as carbohydrates [10]. The general process of green synthesis of leaf extract-conjugated zinc oxide nanoparticles is shown in Figure 1.

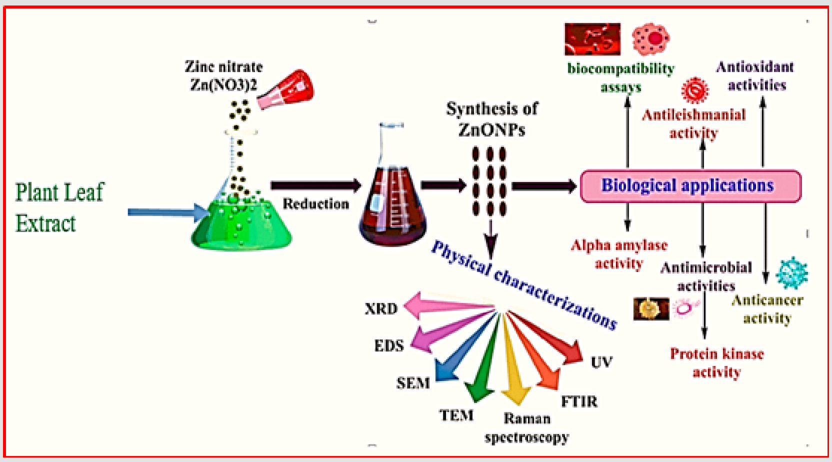

Figure 1: The general process of green synthesis of leaf extract-conjugated zinc oxide nanoparticles [11].

Antimicrobial Applications of Green Synthesized ZnO NPs

Green nanotechnology for ZnO NPs synthesis has resulted in substantial improvements in the antibacterial properties. Green-synthesized ZnO NPs are regarded as viable nanomaterials (NMs) that may be utilized to target microbial infections, damage cancer cell membranes, or transport various chemicals to sick tissue. Nanotechnology has been developed as a revolutionary strategy for combating bacterial infections. The antibacterial capabilities of NMs such as high reactivity and a wide surface area to volume ratio, allow them to interact with a large number of ligands on the NPs' surface, and with receptors on the bacterial surface [11]. The antimicrobial activity mechanism of ZnO NPs is shown in Figure 2. An innovative technique for synthesizing ZnO NPs with Cassia fistula plant extracts as capping agents, consisting of components such as polyphenols (11 percent) and flavonoids (12.5 percent). The ZnO NPs of 5 to 15 nm with hexagonal rotzite structure were easily produced. ZnO NPs absorption band at 359 nm is shown in Figure 3. Attributed to absorption from the ZnO intrinsic band-gap. Zinocutate biology ZnO NPs have recently been shown to be a unique decaying and capping agent utilizing the floral extract Trifolium pratense. The produced ZnO NPs with a range of dimensions 60–70 nm demonstrated the antibacterial effectiveness against S. aureus, E. coli and P. aeruginosa clinical and standard strains The antimicrobial impact was assessed by the zone of inhibition technique indicates that there was a substantial antibacterial activity of the different conc. of ZnO NPs coated cotton fabric was observed against Aspergillus niger, Staphylococcus aureus, and Escherichia coli. is shown in Figure 4.

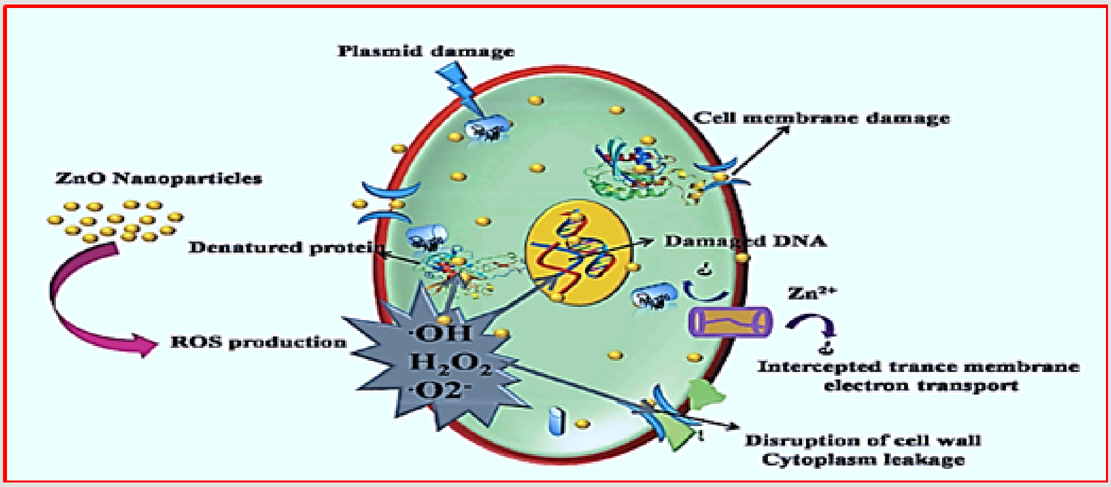

Figure 2: Schematic representation of antimicrobial the activity of ZnO NPs [13].

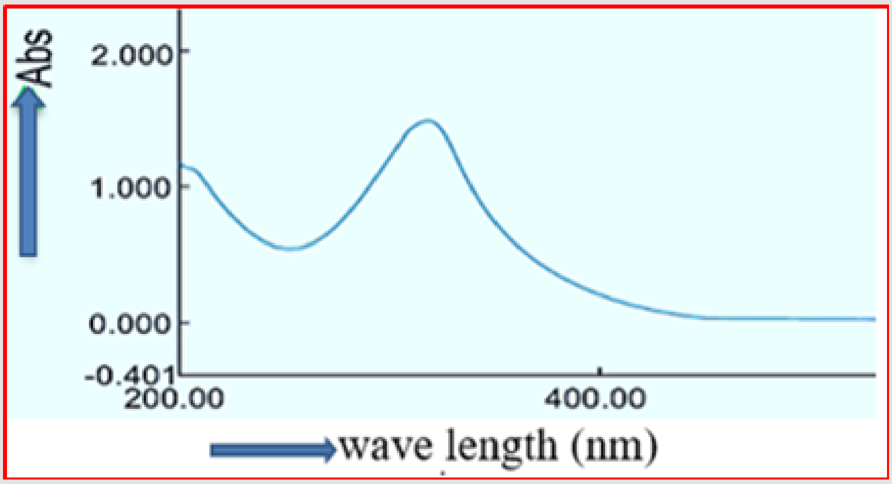

Figure 3: UV-Vis absorbance spectrum of ZnO NPs (359 nm) [14].

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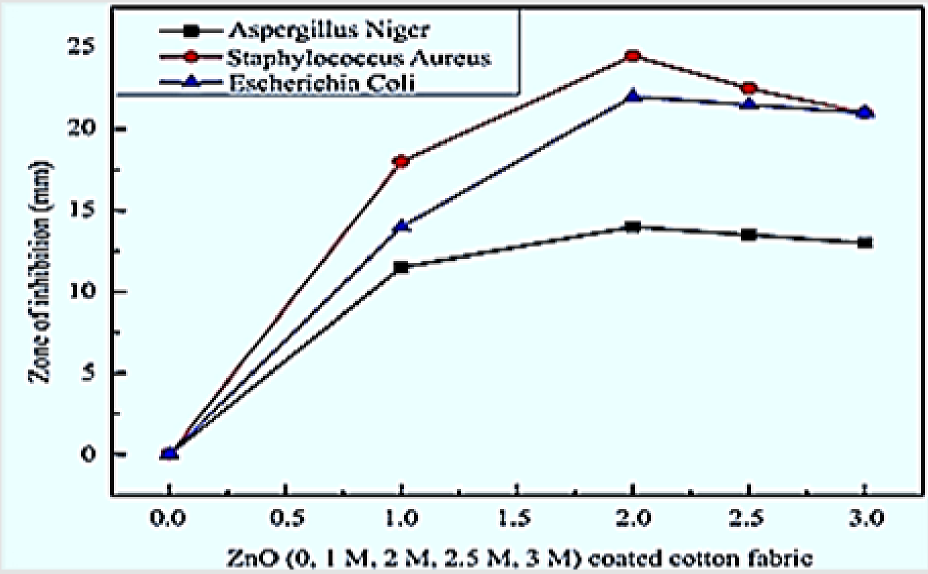

Figure 4: Zone of Inhibition Vs different concentrations of the ZnO coated Cotton Fabrics for the *Aspergillus niger*, *Staphylococcus aureus*, and *Escherichia coli* [15].

The low-cost green production of the ZnO NPs utilizing a leaf extract of the Azadirachta indica (Neem) was another intriguing discovery, generating pure spherical NPs ranging between 9.6 and 25.5 nm. S. aureus, Streptococcus pyogenes, and E. coli were determined through the shake flask technique, and the bacterial growth declined as the concentration was raised. The NPs showed a pattern that verified the hexagonal rotten structure while SEM pictures showed that the neem extract concentrations increased to between 9 and 40 nm, transforming mushroom-type hexagonal discs into bullets, balls, bundles, and closed pinecone shapes throughout the samples. FTIR examination indicated that steroids, terpenoids, flavonoids, phenyl propanoides, phenolic acids, and enzymes contained in the extract were stabilizing the NPs. The mechanism of size reduction and stabilization of ZnO NPs during the biosynthesis fabrication scheme using Neem leaf extract is shown in Figure 5 [12-16].

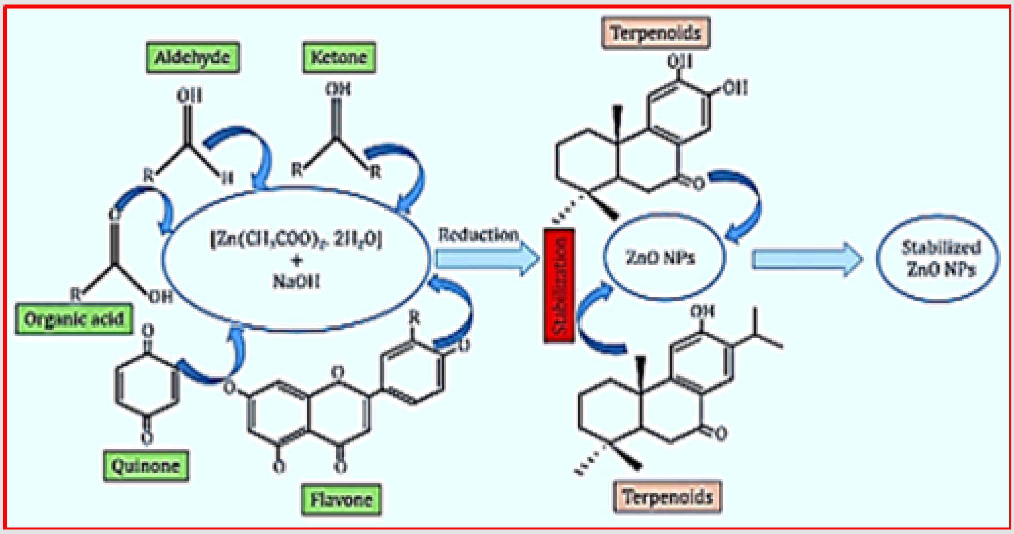

Figure 5: Schematic representation of the mechanism of size reduction and stabilization of ZnO NPs during the biosynthesis fabrication scheme using Neem leaf extract [16].

Conclusion and Future Prospects

One of the most significant challenges of global health care is the development of antibiotic resistance of micro-organisms. Metal oxides NPs are a successful means of overcoming microbial antibiotic resistance. Numerous studies have shown the high antibacterial potential of zinc oxide nanoparticles (ZnO- NPs) concerning gram-positive and gram-negative bacteria. Nanoparticles of zinc oxide have considerable antimicrobial potential. Chemical and physical approaches are utilized to synthesis NPs, however, biological techniques for high productivity and purity are preferable owing to their environmentally friendly, clean, safe, cost-efficient, simple, and efficient sources. The green synthesis of NPs does not need high pressure or temperature, toxic and dangerous chemicals, as well as the inclusion of external reducing, stabilizing, or capping agents, are avoided. The great efficacy of plant extracts as stabilizers and reducing agents for the production of controlled material is demonstrated (i.e., controlled shapes, sizes, structures, and other specific features). The projected green nanoparticle synthesis should be further research and development focused on extension on an industrial scale to laboratory-based work. 'Green' nanoparticles syntheses are probably widely utilized in antimicrobial applications such as the pharmaceutical industry, food industry, and cosmetics. In the future, it is conceivable to utilize packages with integrated zinc oxide nanoparticles to prevent food spoiling and the development of germs. The usage of ZnO NPs containing medical dressing materials will minimize microbial contamination and promote an early cure. Zinc oxide nanoparticles might therefore be regarded as an antibacterial agent of the potential new generation.

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